# List of Figures

**Figure 1.1.1** The diagram shows the name and the applications in different frequency ranges. The THz gap lies between photonics and electronics regimes, which marked as a red area. ----------14

**Figure 1.2.1** The general setup of the antenna-based time domain spectroscopy system. ----------14

**Figure 1.2.2.1** A sample of the electro-optical detection in THz time domain spectroscopy system. ----------15

**Figure 1.3.1** Schematic representation of molecular order in rod-like and disk-like nematic. The average direction is labeled as director, $\hat{n}$. ----------16

**Figure 1.3.2** The three types of the deformation in nematic. ----------16

**Figure 1.3.3** The angle, θ, between the long axis and the polarization of the incident electromagnetic wave will affect the effective index of refraction, which the incident light can see. ----------17

**Figure 1.3.4** The refractive indices of 5CB in visible range. The circles and open circles are $n_o$ and $n_e$ respectively. ----------18

**Figure 2.2.2.1** The sketches of reference cell (a) and the LC cell (b). The substrates are fused silica plates and the alignment of LC cell is homogeneous. ----------43

**Figure 2.3.2.1** The pictures of the temperature-controlled sample holder, which consists with a copper oven (inside) and a Teflon cover (outside). ----------44

**Figure 2.3.2.2** The testing result of the temperature control system. The inset shows a extended window from the dash frame. ----------45

**Figure2.3.2.3** (a) The temporal profiles of the THz signals before (solid line) and after (dash line) purging. (b) The power spectra of the THz signals before (solid line) and after (dash line) purging. Several absorption lines of water vapor appear before purging. (RH: Relative Humidity) ----------46

**Figure 2.5.1.1** The measured time domain signals of THz waves, which pass through the reference cell, LC cell with e-ray (a) and LC cell with o-ray (b) at 25 ºC. ---47

**Figure 2.5.2.1** The $n_o$, $n_e$, $\kappa_o$ and $\kappa_e$ are the real part and imaginary part of the optical constants of 5CB at 25 °C. The circles and the open circles are the extraordinary and ordinary indices respectively. ----------48

**Figure 2.5.2.2** The real part of the indices in the temperature range of 25°C -35°C.

----------49

**Figure 2.5.3.1** The temperature dependence of 5CB in several fixed frequencies of 0.187, 0.219, 0.250, 0.281, 0.312, 0.344, 0.375, 0.406, 0.437, 0.469, 0.500, 0.531, 0.562, 0.593, 0.625, 0.656, 0.687, 0.716, 0.750, 0.781, 0.812, 0.843, 0.875, and 0.906 THz. The circles and the open circles are the $n_e$ and $n_o$, respectively and the stars are

the index in isotropic phase. The solid lines are the average index of $\frac{2n_o + n_e}{3}$ at the temperature below $T_c$. ----------51

**Figure 2.5.4.1** The birefringence of 5CB from Fig. 2.5.3.1. The curves are the fitting results. ----------55

**Figure 2.6.1.1** The frequency dependence of the real part refractive index of 5CB. ----------56

**Figure 2.6.1.2** The frequency dependence of the imaginary part refractive index of 5CB. ----------56

**Figure 2.6.1.3** The frequency dependence of the birefringence of 5CB. --------57

**Figure 2.6.1.4** The room-temperature (a) extraordinary (red circles) and ordinary (blue circles) refractive indices, (b) birefringence, and (c) imaginary extraordinary (blue circles) and ordinary (red circles) refractive indices of E7 are shown as a function of frequency between 0.2 to 1.2 THz. ----------58

**Fig. 2.6.2.1** The real index of 5CB measured by the THz-TDS system without drying. The THz beam passed through the sample is collimated beam and with normal incidence. ----------59

**Figure 2.6.3.1** The temporal profiles of the THz signals recorded at different time for checking the repeatability. ----------59

**Figure 2.6.3.2** (a)The power spectra of the THz signals shown in Fig. 2.6.3.1. (b)The phase difference between two THz signals shown in Fig. 2.6.3.1.----------60

**Figure 2.6.3.3** The measured refractive indices of fused silica in THz range.-------61

**Figure 2.6.3.4**. The complex optical constants of 5CB from 2-mm-thick cell measured in isotropic phase. The solid line and the dash line are the real and imaginary part respectively. The circles and open circles are the measured indices from thin sample, which have been shown in Fig. 2.5.2.1. ----------61

**Figure 3.3.1** A schematic diagram of a THz phase shifter using a LC 5CB cell. The inset shows the top view of 5CB cell. The gray areas show the coated gold strips as the electrodes. ----------78

**Figure3.3.2.1** (a) The measured terahertz temporal waveforms transmitted through 5CB LC cell with various bias fields. (b) An expanded view of Fig. 2(a) in the time window of 5.28 to 5.34 ps. ----------79

**Figure 3.3.2.2** The phase shift of the terahertz wave against bias fields applied to 5CB cell. ----------80

**Figure 3.4.1.1** The schematic diagram of a THz phase shifter using a LC cell. -----81

**Figure 3.4.2.1** The structures of LC cells used in the THz phase shifter. The substrates are fused silica plates. The Teflon spacers are used for controlling the thickness. (a) The cell with one layer of LC, and (b) the cell with two layers of LC called sandwich cell. ----------81

**Figure 3.4.3.1.1** The measured THz waveforms transmitted through a 1-mm-thick 5CB LC cell at various magnetic inclination angles. ----------82

**Figure 3.4.3.1.2** The phase shift of the THz waves passing through the 1-mm LC cell versus the magnetic inclination angle $\theta$ at various frequencies. The solid curves are from the theoretical predictions. The symbols ●, ○, ▲ and Δ correspond to experimental data at frequencies 1.025, 0.805, 0.512 and 0.293 THz, respectively. ----------82

**Figure 3.4.3.1.3** The phase shift of THz waves (f=1.025 THz) passing through the 1.5-mm-thick LC cell versus the magnetic inclination angle. ----------83

**Figure 3.4.3.2.1** The measured THz waveforms transmitted through the LC phase shifter at various magnetic inclination angles. The inset shows the spectrum of the THz signal. ----------83

**Figure 3.4.3.2.2** The phase shift of the THz waves versus the magnetic inclination angle. The solid curves are theoretical predictions. The open circles and circles are experimentally measured phase shift at 0.49 and 1.025 THz. ----------84

**Figure 4.2.1** The general structure of Lyot filter: a birefringence plate placed between a pair of parallel polarizers, whose polarization axes are parallel to each other and at 45º to the optic axis of the birefringent plate. ----------99

**Figure 4.2.2** (a) shows the transmittance spectrum of a 16 $\lambda$ plate, (b) that of an 8 $\lambda$ plate, etc, with (e) showing that of a full-wave plate. Figure 4.2.2 (f) shows the transmittance spectrum of the combination: the product of the transmittance curves (a)-(e), illustrating the peak at $\lambda_0/\lambda$=2 [21]. ----------100

**Figure 4.3.1.1** The schematic diagram of the LC-based Lyöt filter: The fixed retarder (inset (a)) consists of a homogeneous LC cell, which sandwiched by a pair of platy magnets. The tunable retarder (inset (b)) consists of a homeotropic LC cell and a magnet. ----------101

**Figure 4.3.3.1** The calibration of TRA and TRB with the Δτ versus magnet angle. The open circles and circles are the measured data and the curves are the fitting results. ----------101

**Figure 4.4.1** The transmitted spectrum of the THz waves by applying FFT on the measured temporal THz signal. The measured THz signal is shown in the inset. The circles are the measured results and the curve is theoretical prediction from Eq. (4.3.3). ----------102

**Figure 4.3.2** The measured temporal THz signals with $\Delta\tau_A$=1.8, 2.2 and 2.6 ps.---102

**Figure 4.4.3** The peak transmitted frequencies of filter versus $\Delta\tau_A$. The circles are the measured results and the curve is theoretical prediction from Eq. (4.3.3). ----------103

**Figure 4.4.1.1** The profiles of the temporal THz signals versus the azimuthal angle. ----------103

**Figure 4.4.1.2** The THz electric fields of e-ray and o-ray versus ϕ. The open circles and open triangles are the measured results from o-ray and e-ray, respectively. The curves are the theoretical predictions from Eq. (4.5.1.1) and Eq. (4.5.1.2) and measured data.----------104